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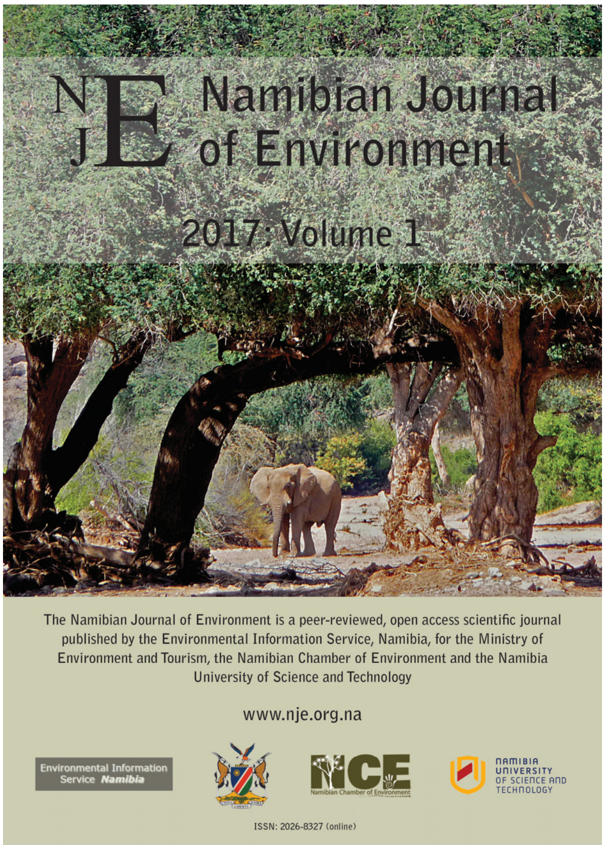

SECTION B: OPEN ARTICLES

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Options to improve soil fertility with national resources

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Abstract

Most fertilisers applied to Namibian crop fields are imported, yet Namibia has vast resources that could be used to improve soil fertility. Organic fertilisers such as animal manure and compost could be sourced from farms, or grown on the crop fields, such as green manures and fertiliser trees, or harvested from nature, such as kelp and guano, or sourced from abattoirs or other agricultural processing facilities, such as blood, bone, horn, feather, fish and seed meals. Inorganic fertilisers are usually sourced from quarries or mines on land, while others can be extracted from seawater or salt. Some locally-sourced fertiliser materials could be applied directly to the soil, perhaps after simple processing such as crushing or milling, or after more complex processing such as through chemical reactions. Rock salt and brine solution have been analysed to assess their suitability for extraction of nutrients from which to manufacture chemical fertilisers as by-products of purifying the salt for industrial uses. It is important that harvesting of rock salt and brine from pans north of Cape Cross be done without disrupting the natural regeneration through underground connection to the sea, to ensure sustainability of these valuable resources. Labelling of fertilisers should include a breakdown of the major elements contained, so that farmers who test their soils could determine appropriate application rates to balance minerals that will produce crops of good quality.

Keywords: by-products, fertiliser, inorganic fertiliser, manure, organic fertiliser, productivity, soil fertility

Introduction

The nutritional quality of crops has steadily worsened in the last decades, due to decline in soil fertility resulting from unsustainable farming practices. Studies that show decline in mineral content of agricultural products, such as that by Thomas (2007), usually use data from the 1940s as their baseline, since this is when laboratories started measuring the mineral contents of crops. However, there were warnings of decline in soil fertility taking place well before then (Hensel 1894), so the benchmark mineral contents of crops should actually be higher. The consequences of declining soil fertility are not only weaker crops and worsening human health, but also greater outbreaks of pests (Chabboussou 2004) and weeds (Gilman 2011).

Soil fertility is contributed to by both mineral and non-mineral elements. The mineral elements tend to cycle between rocks, soil, water and living organisms. The non-mineral elements, such as C, H, O and N, tend to cycle between the soil, water, living organisms and the atmosphere. Soil fertility improves when plants grow and their minerals get recycled on the land. With the help of beneficial soil microorganisms and the humus flywheel (Lovel 2014), plants take up mineral elements from the soil, combine them with the non-mineral elements to form organic matter, which then gets broken down to recycle the elements. Conversely, soil fertility declines when plants are harvested and removed from the land or prevented from growing (Andrews 2006). If there are insufficient plants to protect the soil, weathering results in most of the non-mineral elements ending up in the atmosphere and most of the mineral elements being washed into water bodies such as pans and the ocean.

Namibian soils tend to lack fertility, being very old and mostly sandy. Namibia also lacks volcanic activity, which renews mineral soil fertility in other parts of the world. In the past, an abundance of birds and animals used to bring some of the fertility that had been washed into the oceans back inland (Shepard 2012), but their numbers have greatly decreased due to various human influences. Therefore, it is necessary for soil fertility to be restored by other means in order to grow good quality crops.

Most fertilisers applied to Namibian crop fields are imported, yet Namibia has vast resources that could be used to improve soil fertility. Organic fertilisers such as animal manure and compost could be sourced from farms, or grown on the crop fields, such as green manures and fertiliser trees, harvested from nature, such as kelp and guano, or sourced from abattoirs or other agricultural processing facilities, such as blood, bone, horn, feather, fish and seed meals. Inorganic fertilisers are usually sourced from quarries or mines on land, while others can be extracted from seawater or salt. Some locally sourced fertiliser materials could be applied directly to the soil, perhaps after simple processing such as crushing or milling, while others would first need to undergo more complex processing, such as through chemical reactions.

Soil microorganisms play important roles in making nutrients available to crops. Soil amendments that favour beneficial microorganisms therefore enhance the efficiency of fertilisers. Most Namibian soils are low in cation exchange capacity (CEC) because they lack sufficient clay or humus to adsorb sufficient cations. Small quantities of humic substances such as fulvic and humic acids could be used to amend soil and raise its CEC, but this usually implies high cost. Although many forms of organic matter would be cheaper, much larger quantities would be required and their benefits would be short-lived unless reapplied annually. Clay or biochar may offer cheaper alternatives, and combinations may offer synergies.

Fertilisers from organic sources

Animal manure

The quality of manure varies tremendously, depending largely on the quality of food eaten by the animals producing the manure. Those that feed on insects or sea fish tend to produce the best-quality manure, such as guano from bats and sea birds. Dairy cows tend to produce the best-quality manure among ruminant animals, because they usually feed on good-quality pastures or fodder. Animals perform the function of spreading manure and urine as they graze on pastures or residues remaining in crop fields after harvest. Mobile night kraals can be moved around crop fields to spread the fertility (Sibanda et al. 2016). However, fresh manure will lose quality if left above ground (Figure 1). Dung beetles perform the function of getting fresh manure underground if they are given the chance to do so (Walters 2008).

Figure 1: *The quality of manure deteriorates if it is left exposed to the sun.*

Green manure

The greater the diversity of cover crops (Clark 2007) grown for green manure, the more effectively the soil's fertility can be enhanced. Legumes fix nitrogen while grasses grow massive root systems. Dicotyledonous species tend to specialise in particular minerals that their taproots bring from deep underground, while grasses are more generalist, with their roots bringing up a greater diversity of elements (Walters & Fry 2006). Ploughing in of cover crops disturbs the soil and only results in temporary increase in soil carbon before it gets rapidly broken down. No-till or minimum tillage allow for longer-term build-up of soil carbon and fertility. However, if glyphosate herbicide is applied to terminate the cover crop in preparation for growing the production crop, then soil fertility may be harmed by chelation of some mineral elements (Eker et al. 2006). This harm could be avoided by mowing the cover crop, although it may then get blown away by the wind. Use of a roller-crimper (Kornecki & Price 2010) could inactivate and lay down the cover crop, while leaving it firmly rooted in the ground. This also occurs if animals graze down the cover crop, with the added advantages of spreading beneficial microorganisms in their dung and diversifying farm income. Weeds may also be helpful in bringing minerals that a soil is short of from underground to the top soil, if slashed and left to decompose on the surface (Gilman 2011). Smallholder farmers in the tropics, including those in semi-arid regions, often develop cover crop systems that are grown together with their production crops (Bunch 2012).

Trees

Tree species with deep taproots are also effective green manure plants (Leakey 2012), sourcing minerals from deeper soil horizons than herbaceous plants are able to do. In addition, they provide the extra advantage of breaking the speed of the wind and reducing temperature extremes for crops growing in their vicinity, which becomes more critical with climate change (Nabhan 2013). Farmers usually select multi-purpose tree species for growing in or around their crop fields, to provide various products and perform different functions (Leakey 2012). Leguminous trees that regrow vigorously, preferably without thorns, are useful for "chop and drop" mulching (Thurston 1997). Tall-canopied trees, such as *Faidherbia albida* (Figure 2), which is commonly known as the fertiliser tree, literally cover crops (Umar et al. 2013). If their canopies grow too dense and shade the crops excessively, they can be pollarded by chopping their branches high up, from where new branches will regrow. An added benefit of chopping trees that grow among crops is that the tree roots respond by excreting sugary exudates which feed soil microorganisms, which subsequently feed the nearby crops (Huang et al. 2014). If rows of trees are planted in crop fields, they can either be aligned at right angles to prevailing winds, or along contour ditches where they could also benefit from harvested rain water (Zimmermann et al. 2015).

Figure 2: *A large canopy of* Faidherbia albida *protects nearby fruit trees from frost at Kaisosi.*

Compost

Compost is usually uneconomical to use on agronomic fields, unless it is diluted through use of aerated compost tea and the microorganisms are fed by roots of cover crops. On the other hand, compost may be economical on horticultural fields if the farmer has insufficient land to restore soil carbon and eliminate soil pests and diseases by rotating with diverse cover crops. The quality of compost depends largely on the quality of ingredients used to make it, assuming that the correct

carbon to nitrogen ratio of roughly 30:1 in the starting materials has been used. Clay or crushed biochar at 1-2% of the starting volume is also an essential ingredient if real humus is to be formed in the compost (Solomon 2013). Composted animal manures from feedlots and poultry houses need to be checked for contamination with chemicals and excessive micro-elements that may have been used in raising the animals.

Bone meal

Bone meal is a good source of calcium and phosphorous, while also containing a small amount of slow-release nitrogen (Table 2). However, there needs to be good microbial activity in the soil to break down the bone meal and release its elements. Dry bones can also be added to the organic matter when producing biochar. The charred bones are usually soft enough to crush by hand to produce excellent quality biochar.

Horn meal, blood meal, fish meal, feather meal, seed meal and seed cake

If horns and dried blood from abattoirs, fish wastes from fish processing factories, feathers from poultry abattoirs and oilseeds or oilseed cake (Figure 3) are milled into meal, they become valuable fertilisers that release nitrogen and phosphorous slowly. However, some of them may be too costly for direct application to soil, especially for those with competing demand as animal feed. Value addition could take place by using these as animal feed and then applying the resulting enriched animal manure to the soil, or allowing the animals to spread it over the soil for processing by dung beetles.

Figure 3: *Sunflower seed cake produced at Shadikongoro.*

Figure 4: *Kelp washed up on the beach near Swakopmund*

Kelp

The mineral-rich Benguela current ensures rapid growth of kelp (Figure 4) in waters along much of Namibia's coast. It used to be harvested, washed, dried and milled in Lüderitz, but sadly that seems to be no longer the case. The high diversity of micro-nutrients in kelp makes it valuable as an animal supplement and fertiliser. The latter also because of its auxins, gibberellins, and cytokinins, which are hormones that promote plant growth (Fry & Simmons 2005). Kelp can be applied to soil as a meal, or as a liquefied emulsion that can also be applied directly to crops by foliar spraying. Alternatively, value could be added by feeding kelp to animals and then using the enriched manure on the soil.

Fertilisers harvested from inorganic sources

Rock dust

Wherever rocks are processed, such as being crushed, ground or sawn, the powder or dust that is produced might have fertiliser properties, especially if from igneous rock (Lisle 1994, Moore 2001). Rock dust could be sourced from sediment of mine tailings dams or from rock-processing industries scattered throughout Namibia (Figure 5). It is not only the presence of mineral elements that provide fertility, but also the paramagnetic properties of some rock dusts that enhance plant growth (Callahan 1995). However, there is also a danger that rock dust may contain toxic elements, such as excessive fluorine, heavy metals or radioactivity, which therefore need to be checked for before being used as fertiliser.

Lime

Most lime that is mined and crushed in Namibia, such as around Tsumeb, is dolomitic lime (Figure 6) which is high in magnesium. This may be appropriate for loose sandy soils, because it helps them to become firmer. However, this causes the soils with more clay to become too tight and compacted, requiring frequent ripping. For such soils, calcitic lime would be more appropriate (Andersen 2010). The lime deposits east of Henties Bay may be a suitable source of calcitic lime.

Figure 5: *Granite dust being collected outside a factory in Brakwater where the granite is sawn*

Figure 6: *Spreading of dolomitic lime at Ndonga Linena*

Gypsum

Gypsum is comprised of calcium sulphate and therefore supplies both calcium and sulphur, which both contribute to soil fertility when they are present in sufficient quantity and balance. They enhance the efficiency of other elements supplied by more expensive fertilisers, thus saving on costs (Tiedjens 1965).

Seawater or rock salt

Dilute sea water has been used to good effect to improve soil fertility and the nutritional value of the crops grown (Murray, 1976; Walters, 2005). However, extreme care is required to avoid contaminating the soil with excessive sodium, especially in soils experiencing high evaporation rates and low carbon content. There are ways to remove most of the sodium and remain with most of the high diversity of valuable micro-elements. One way is to allow sea water to evaporate in shallow pans, where sodium chloride and a few other salts crystallise on the surface, after which the brine solution underneath is syphoned out for its valuable micronutrients (Amena 2006). Another way is to raise the pH of seawater to between 10.60 and 10.78, whereupon a precipitate containing the valuable micronutrients settles to the bottom, leaving the sodium and chloride ions dissolved in the water above, which may then be syphoned off (Taylor 2007).

Fertiliser by-products of chemical manufacturing from local inorganic and organic sources

There are many opportunities for chemical manufacturers to broaden their scope and capacity to serve Namibia's agricultural industry. The first project that we have embarked on is to work with the salt industry to produce nutrients as a by-product in the production of pure salt.

The extraction of chemicals and production of fertilisers from sea water and rock salt

The process involves the removal of valuable nutrients such as potassium and magnesium that are present in seawater and rock salt. The two methods being developed to achieve this are indicated in Figures 7 and 8. Ideally all by-products from the processing should be put to use, so that the refinery has zero or minimal waste to dispose of.

Samples of various types of rock salt were collected north of Cape Cross and analysed to determine chemicals and fertilisers that could be produced and to predict the volumes of minerals that could be derived. Results from the analysis are given in Table 1. One of the research objectives was to see what the possibilities are of adding rock salt to brine solution to speed up the crystallisation process and recover some of the more valuable chemicals contained in the rock salt, such as potassium, magnesium, barium sulphate and calcium carbonate.

Potassium can be economically recovered from potassium-bearing brines by dissolving the rock salt in a brine solution (which also contains potassium) and then precipitating the potassium as $KClO$ by the addition of sodium hypochlorite. Potassium is a very valuable agricultural product. Magnesium can be recovered as magnesium hydroxide by the addition of sodium hydroxide. Magnesium is also valuable as it is used extensively in metal alloys and in addition it has agricultural value. It is also used as magnesium chloride for the extraction of marine phosphates. Magnesium is also the central atom in chlorophyll and is a constituent of several plant oils, among others. Barium sulphate is also recovered by precipitation. It has medicinal value and is also used in oil drilling. Precipitated calcium carbonate can also be recovered from brine solutions and has multiple uses in agriculture and other industries, particularly in refining of metals and production of cement.

The analysis of rock salt and brine solution gives a clear picture of what has to be removed in order to produce a salt suitable for the Chlor/Alkali process. It indicates that very pure salt can be economically produced as a result of the recovery of by-products which have industrial, agricultural, as well as other applications. These analyses have also provided us with data to assess more accurately the extent of these resources.

The rock salt deposits north of Cape Cross regenerate through underground connection with the sea. We estimate that these rock salt deposits could sustainably yield 36,000 tons of gypsum and 2 million tons of salt per year, from which could

Table 1: *Analysis of rock salt and soils from north of Cape Cross, on a dry mass basis. (The seven samples are: 1. ML. 147 Cape Cross SA 9/1 Rock Salt @ 0-0.1 m depth; 2. ML. 147 Cape Cross SA 13/2 – Black Rock Salt; 3. SA 9/2 147 Rock salt out- crop; 4. SA 5-1 soil impregnated with salt; 5. SA 4-1 Soil impregnated with salt; 6. ML 147 Cape Cross SA 14/2 @ 0.25 – 0.7 m; 7. ML 147 Cape Cross SA 14/1 @ 0-0. 2M)*

Sample no:	1	2	3	4	5	6	7
Assay, as NaCl, % m/m [LABS 008]	74.98	95.29	96.16	96.75	92.15	98.17	97.63
Sulphate, as SO_4, % m/m [LABS 005]	2.3	1.16	1.25	0.96	2.35	0.67	0.28
Calcium, as Ca, ppm [LABS 004]	10 430	4603	4865	3790	10 030	2423	1017
Magnesium, Mg, ppm [LABS 004]	318	101	35	246	346	596	375
Ca:Mg Ratio	33:1	46:1	139:1	15:1	29:1	4.1:1	2.7:1
Insoluble Matter, % m/m [LABS 003]	19.49	2.85	0.89	0.37	3.87	0.12	0.02
Total Nitrogen, as N, ppm [Kjeldahl method]	153	111	99	131	107	124	95
Iron, as Fe, ppm [LABS 001]	2	3.7	0.6	2.9	1.1	1	1.3
Chromium, as Cr, ppb [LABS 001]	33	49	23	43	<20	<20	<20
Bromine, as Br, ppm [LABS 007]	13	25	13	52	11	82	78
Aluminium, as Al, ppm [LABS 001]	1	1.3	0.3	1.7	0.6	0.7	0.6
Silica, as SiO_2, ppm [Colourimetric]	9.8	9.9	9.9	1	10	1	2
Potassium, as K, ppm [AA]	238	183	150	289	330	508	355
Strontium, as Sr, ppm [ICP]	131	50	101	40	380	17	9.4
Heavy Metals, ppm [Calculation]	3	5.2	0.9	4.7	1.8	1.8	2
Ammonia, as NH_3, ppm [Kjeldahl method]	1.3	1.2	1.2	1.2	1.2	1.2	1.3

*For all samples, the concentrations of following were found to be: nickel (Ni), molybdenum (Mo), manganese (Mn), copper (Cu) and lead (Pb) <0.1 ppm; iodine (I) <0.4 ppm; vanadium (V) <20 ppm; titanium (Ti) <1 ppm; fluorine (F) <0.5 ppm; total alkalinity, as Na_2CO_3 and %carbonates, as Na_2CO_3 <0.1%m/m.

be extracted 1,460 tons of potassium chloride, 6,100 tons of magnesium chloride and 3,800 tons of barium chloride. However, if indiscriminate mining disrupts the natural regeneration process, then these valuable resources will soon become depleted.

Methods to extract specific minerals used in agriculture from seawater, brine solutions and rock salt

The Swiss (Krebs) SALEX process is used to produce pure salt (sodium chloride) required by the Chlor/Alkali process by the removal of other unwanted salts that have agricultural use. These include magnesium hydroxide, potassium salts, barium sulphate and calcium carbonate. There is also a fairly recent process developed at the Great Salt Lake in Utah to extract potassium from brine solutions (Orris 2011).

We have now designed an extraction and integrated salt purification and value addition process shown schematically in Figures 7 and 8. It has a dual function to produce a pure sodium chloride salt suitable for producing chemicals from, and to extract potassium, barium, calcium carbonate and magnesium hydroxide from rock salt, brine solutions and seawater.

The process can be implemented in two ways. The first way, indicated in Figure 7, extracts all the salts together. The second way, indicated in Figure 8, extracts each salt separately.

The manufacture of super phosphate

There are no large rock phosphate deposits in Namibia. There are large deposits of marine phosphate and currently the proposed utilisation of these resources has evoked much controversy. The alternative, until some kind of clarity is established, is to use bone meal to produce a super phosphate and to mix it with guano.

Bone ash is produced by burning bone meal (while capturing the generated energy) and reacting it with sulphuric acid, which is currently produced in Namibia by the copper smelter in Tsumeb. The bone ash contains approximately 42% phosphate and 55% calcium.

$$\underset{\text{From bone ash}}{Ca_3(PO_4)_2} + \underset{\text{Sulphuric acid}}{2H_2SO_4} \rightarrow \underset{\text{Monocalcium phosphate}}{Ca(H_2PO_4)_2} + \underset{\text{Gypsum}}{2CaSO_4}$$

This form of phosphate is more soluble than that in bone meal. It also contains a number of trace elements such as Al, Ba, Fe, Mg, Mn and Ti. This can be mixed with guano, the N, P and K contents of which appear in Table 2.

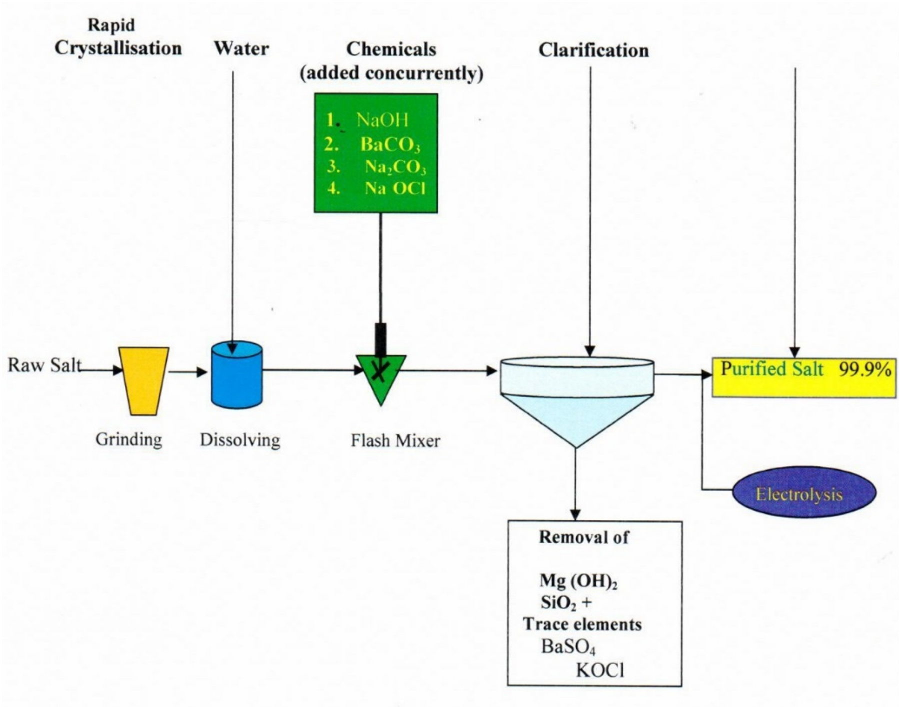

Figure 7 (left): *The combined precipitation option to process rock salt into purified salts, extracting all the salts together.*

Figure 8 (below): *Second option of processing rock salt into purified salts which can each be extracted each separately and then used to manufacture fertilisers, as indicated in the text*

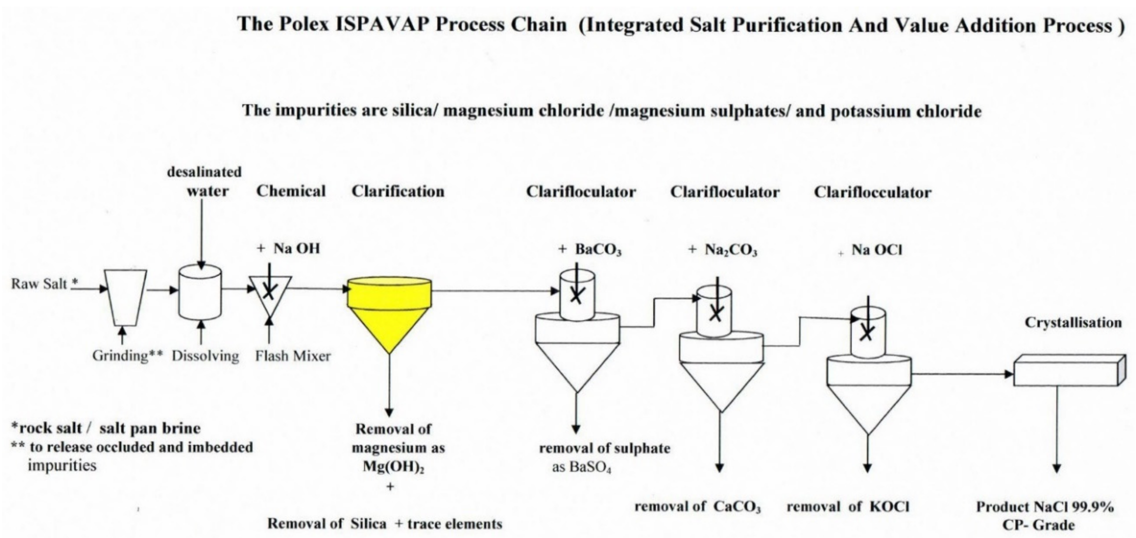

Table 2: *Percentage of major elements provided by various types of Namibian fertilisers. Blank cells do not necessarily represent zero, but rather data that are unavailable.*

	Percentage of element in the fertiliser							
Type of fertiliser	N	Ca	Mg	K	Na	P	S	Fe
Bone meal	4.0	21.0				10.0		
Compost (Gottesgabe Buschprodukte)	0.5	1.1	0.1	1.0				0.6
Vermicompost (Gottesgabe Buschprodukte)	1.0	0.6	0.1					
Guano (Seabird Guano)	15.3			2.0		4.3		
Sunflower seed cake	4.2	0.1	0.1	0.3		0.7		
Dolomitic lime (from near Tsumeb)		20.0	14.0					
Calcitic lime (from east of Henties Bay)		45.2	0.2					
Gypsum (Elspe Minerals)		17.7	0.2	0.5	0.3		13.7	0.4
Rock salt		0.1	0.2	0.1	37.0		0.3	
Kelp	0.8	2.2	0.8	5.7	5.8	0.3		0.2

Manufacture of calcium nitrate

Calcium nitrate can be used as a fertiliser from the reaction:

$$\underset{\text{Limestone}}{CaCO_3} + \underset{\text{nitric acid}}{2HNO_3} \rightarrow \underset{\text{calcium nitrate}}{Ca(NO_3)_2} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2}$$

Manufacture of ammonium nitrate, calcium ammonium nitrate and ammonium sulphate nitrate

Ammonia gas is dissolved in water to produce ammonium hydroxide. Because ammonia is used extensively in the uranium industry and the explosives are expensive, it is viable to manufacture ammonia and from this to make ammonium nitrate. Ammonia (NH_3) is normally produced using the Haber process based on the reaction:

$$\underset{\text{Extracted from the atmosphere}}{N_2} + \underset{\text{Produced from gas or electrolysis of water}}{3H_2} \leftrightharpoons \underset{\text{Ammonia}}{2NH_3}$$

The dissolution of NH_3 in water results in ammonium hydroxide (NH_4OH) according to the reaction:

$$2NH_3 + 2H_2O \rightarrow 2NH_4OH$$

The ammonium hydroxide can be reacted with nitric acid (HNO_3) to form ammonium nitrate (NH_4NO_3), which is a fertiliser:

$$NH_4OH + HNO_3 \rightarrow NH_4NO_3 + H_2O$$

Because sulphuric acid (H_2SO_4) is produced in Namibia, it makes it easier to produce ammonium sulphate. This is done as follows:

$$H_2SO_4 + 2NH_4OH \rightarrow (NH_4)_2SO_4 + 2H_2O$$

Calcium ammonium nitrate is made by adding calcite or dolomite to the ammonium nitrate melt before prilling or granulating. Ammonium sulphate nitrate is made by granulating a solution of ammonium nitrate and ammonium sulphate.

Manufacture of urea

Urea fertilisers are produced by a reaction of liquid ammonia with carbon dioxide. The process steps include solution synthesis, where ammonia and carbon dioxide react to form ammonium carbamate, which is dehydrated to form urea; solution concentration by vacuum, crystallization, or evaporation to produce a melt; formation of solids by prilling (pelletising liquid droplets) or granulating; cooling and screening of solids; coating of the solids; and bagging or bulk loading. The carbon dioxide for urea manufacture is produced as a by-product from the ammonia plant reformer.

Potential of producing fertilisers from Kudu gas

Kudu gas would be ideal for production of ammonium fertilisers, such as ammonium sulphate and ammonium nitrate. This is because Kudu gas consists of almost pure methane, unlike most natural gas from other parts of the world that would first need to have its sulphur removed at high cost before its hydrogen could be reacted with nitrogen from the atmosphere through the Haber process to produce ammonia for use in fertiliser production. We believe that it would be more profitable to produce fertilisers and industrial chemicals from Kudu gas than to burn it for energy, additionally more jobs could be created and it would last a lot longer than the predicted 22 years of energy supply (SAIEA 2006). The plentiful sources of renewable energy available in Namibia could rather supply energy needs.

***Multi-nutrient potassium nitrate fertiliser from debushed* Terminalia sericea**

Wood from debushed *Terminalia sericea* is ashed (while capturing the generated energy). The ashes, which are strongly alkaline mainly because of the presence of potassium oxide (K_2O), are treated with nitric acid, which could also potentially be produced in Namibia. This, in addition to forming potassium nitrate, dissolves other nutrients in the ash. The resulting liquid can be "loaded" onto some inert material such as sepiolite or biochar to make a fertiliser that is not too concentrated.

Amendments that improve efficiency of fertilisers

Clay

The low CEC of sandy soils could be raised by mixing in some clay. Small quantities of clay could be sourced from pans and termite mounds. There are a few deposits in Namibia from where larger quantities of clay could be sourced, but at high transport costs. The bentonite clay that is sold for mixing with animal feed is unfortunately sodium bentonite, which would be unsuitable for amending soil due to its sodium content.

Sepiolite

Sepiolite is a type of clay that has many applications including agricultural applications as absorbents and carriers for chemicals and pesticides. Sepiolite improves stability and components suspension of fluid fertilisers in spraying or fertigation applications. Drying at a temperature high enough to remove the zeolitic water in the structural channels improves the sorbent properties. In Namibia, sepiolite deposits are located some 120 km south east of Gobabis in a number of pans.

Biochar

Biochar has the additional benefit over clay of also adsorbing anions and housing beneficial microorganisms. Biochar could be produced on or near crop fields from organic matter such as prunings from trees and crop residues, to use as soil amendment (Taylor 2005), preferably after conditioning by microorganisms (Lehmann et al. 2011). The biochar could be conditioned by composting it (Fischer & Glaser 2012), or throwing it into animal kraals to get mixed with dung and urine, while being crushed by animal hooves (Zimmermann & Amupolo 2013). For further value addition, biochar can be fed to animals, which then spread their manure to be incorporated into the soil by dung beetles (Joseph et al. 2015).

Humic acids

Humic acids are usually extracted from carbon-rich deposits such as leonardite, soft rock phosphate and peat (Lovel 2014). Since these are unavailable in sufficient quantities in Namibia, it may instead be possible to extract humic acids from torrified wood (Foidl in lit.). The wood for torrefaction could be sourced from abundant encroached bushes, which should be harvested in a regenerative manner such as along contour strips (Bruwer 2014).

Microbial inoculants

In soils that lack microbial activity, such as those that have been abused by chemical inputs, it could be useful to apply microbial inoculants such as effective microorganisms (EM) (Higa 1996, Xu et al. 2000). If the soil also lacks sufficient carbon to feed the microbes, then some dilute molasses could be applied to favour bacteria, or woody material to favour fungi. Inoculating crop seed with species-specific nitrogen-fixing bacteria or mycorrhiza fungi (Medina & Azcón 2010), may result in significant yield increases with minimal costs.

Recommendations

If entrepreneurs proceed to make use of the many opportunities that exist in Namibia to harvest, process and sell fertilisers and soil amendments from local resources, it is important to label their products with results from analyses of elements contained in their products, such as those appearing in Table 2, although for all major elements rather than just selected ones. This will allow farmers who have analysed their soils to determine the appropriateness of different fertilisers and calculate application rates to achieve optimal balance of the major elements (Astera 2010, McKibben 2012, Solomon 2013).

The mining of rock salt deposits north of Cape Cross needs to be done with care in a sustainable manner that respects the natural regeneration process through underground connection with the sea. Fertilisers should also be produced from the high-quality Kudu gas.

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